MANAGEMENT STRATIGIES FOR THE REUSE OF WASTEWATER IN JORDAN

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ABSTRACT

Water resources in Jordan are extremely limited and water availability per capita is among the lowest in the world. With the expected growth in population, the already limited supply of fresh water for agriculture will be used to meet the growing demands in urban and industrial regions of the country. The sustainability of irrigated agriculture in Jordan is dependent on efficient irrigation systems such as drip irrigation and marginal water sources such as wastewater generated from wastewater treatment facilities in Jordan. The municipal and industrial water requirements in Jordan are expected to increase by 65% over the next 15 years. While agricultural demands are expected to increase by 5% during the same period. Reuse of treated municipal water is expected to increase to meet the growing urban, industrial, and agricultural demands in the future.

Irrigated agriculture in Jordan is mostly concentrated in the Jordan Valley with optimum climatic conditions that allow for the production of up to three high-value vegetable crops per year. As irrigated agriculture in Jordan becomes more dependent on wastewater and other marginal water sources, the quality of marginal waters used for irrigation must be suitable for crop production. Therefore, the availability of treated wastewater for reuse to meet crop water requirements is dependent on water quality, crop type, irrigation system, and other factors. A computer model was developed to predict the potential contribution of wastewater to crop water use of major cash crops in the Jordan Valley. The model incorporates wastewater quality, irrigation system, crop type, and soil type in estimating the maximum potential contribution of wastewater to crop evapotranspiration. The model estimates the potential quantities of wastewater that can be used to supplement fresh irrigation water for each of the major crops in the Valley. The model can be used to implement sustainable management strategies for the reuse of treated wastewater in the Jordan Valley.

INTRODUCTION

Irrigated agriculture in Jordan has been growing rapidly. The available fresh water supplies in Jordan were approximately 826 million cubic meter (MCM) in 2003 of which 520 MCM were used in agriculture (63.5 % of the total water use in Jordan). Urban water uses accounted for approximately 32.5% while industrial uses accounted for 4%. In the year 2010, the annual

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potential available water resources are estimated to be 1219 MCM, while the estimated total water requirements are expected to increase to 1538 MCM. Irrigated agricultural sector will consume about 68 % of the total available water resources (MWI, 2003). The total available water resources per capita are decreasing as a result of population growth (annual rate of 2.5% in 2004) and are projected to fall from the current 160 m^3/capita/year to about 90 m^3/capita/year by the year 2025.

STUDY AREA

Jordan's total area is about 88,778 km^2, located about 80 kilometers east of the Mediterranean Sea (DOS, 2006). More than 80 % of the country's area is arid and receives less than 200 mm annual rainfall. The average precipitation over Jordan is about 93.6 mm. Generally, the climate is Mediterranean, with a long dry hot summer, a rainy winter, and a relatively dry spring and autumn seasons. Irrigated agriculture in Jordan (76,000 ha) falls under two categories in term of management and source of water. In the highlands (43,000 ha), privately managed individual farms are irrigated by groundwater from private wells. In the Jordan Valley (33,000 ha), the publicly managed irrigation system uses surface water of Yarmouk River and side wadis as well as recycled wastewater. Agricultural development in Jordan depends mainly on the availability and quality of water resources, and this requires further development of irrigation water management (Jitan, 2005).

REUSE OF WASTE WATER IN JORDAN

As irrigated agriculture in Jordan becomes more dependent on wastewater and other marginal water sources, the quality of marginal water used for irrigation must be suitable for crop production. In addition, the quality of marginal water that is discharged into waterways is expected to meet minimum standards to achieve water quality objectives and uses for a particular watershed. The water quality constituents of major concerns for irrigated agriculture in Jordan include suspended sediment, salinity, nutrients (mainly P and N), Na, Cl, SO_4, HCO_3, B, trace elements, heavy metals, pathogens, and high pH.

Some marginal water sources that are not suitable for irrigated agriculture, because of the high load of salts or other constituents such as sodium or chloride, are either discharged into waterways or mixed with fresh irrigation water and used for irrigation. While such waters are not suitable for irrigating vegetable crops, using relatively simple treatment methods could significantly reduce the load of sediment, phosphorus and nitrogen. Wastewater sources that are high in salinity are not suitable for vegetable crops could be used to irrigate forages and field crops.

The reuse of wastewater may provide practical and cost-effective solutions to the increasing demand for additional water in Jordan. The Government of Jordan and the USAID mission in Jordan have identified the reuse of wastewater for irrigation as a high priority issue (USAID Website). Reuse of wastewater and other marginal waters will increase the availability of freshwater for urban and industrial users in Jordan. Irrigated agriculture in Jordan is mostly concentrated in the Jordan Valley with optimum climatic conditions that allow for the production of two to three high-value vegetable crops per year.

WATER QUALITY AND WATER USE ASSESMENT

With the expected increase in population, the amount of reclaimed water or treated wastewater discharged into Wadi Zarqa (King Talal Reservoir) are projected to triple by the year 2025 (McCornick, et al., 2002). Most of this treated wastewater that is discharged into King Talal Reservoir (KTR) and mixed with natural runoff waters, relatively saline springs, and reclaimed water from other urban areas including Amman, the capital of Jordan (McCornick, et al., 2002). The salt and nutrient contents of this water are relatively high and have greater impact on crop production as compared to fresh irrigation water. The quality of KTR water is expected to change in the future because of the expected increase in the quantity of treated wastewater discharged into the reservoir. KTR water is mostly used in the southern part of the Jordan Valley. Water quality parameters of KTR are listed in Table 1. The northern part of the Jordan Valley receives higher quality waters from the Yarmouk River, Mukheibeh wells, and Wadi A Arab Reservoir, and are collectively referred to as King Abdullah Canal (KAC) waters (McCornick et al. 2003). KAC waters are also used in urban areas because of the relatively lower salinity content of the water (Table 1)

Table 1. Water quality parameters of King Talal Reservoir (Grattan, 2000 and McCornick, 2003)

Water Quality Parameter	*Unit*	*KTR (1994-99)*	*KAC (1997-99)*
EC	dS/m	1.9	0.98
PH	-	7.8	8.2
SAR	-	3.8	2.1
TSS	mg/l	20	56
Na	mg/l	190	86
Ca	mg/l	117	71
Mg	mg/l	46	30
K	mg/l	29	8.5
Cl	mg/l	322	124
SO4	mg/l	139	86
HCO3	mg/l	508	282
Total P	mg/l	5.6	0.4
PO4-P	mg/l	4.9	0.3
Total N	mg/l	26.0	4.3
NO3-N	mg/l	2.0	3.1
NH4-N	mg/l	19.0	1.0

Irrigation water quality in the northern part of the Jordan Valley is relatively good and has little to no impact on crop productivity. However, as the demand for water increases in the urban and industrial sectors, the amount of fresh water available for irrigated agriculture will decline. Reuse of wastewater in the northern part of the Jordan Valley will continue to increase. In the southern part of the valley, the quality of water available for irrigation is relatively high in salinity and other constituents that require careful selection of appropriate crops, irrigation systems, and management practices to maintain productivity.

Assessment Method

The hazard index concept has been used to establish a vulnerability assessment process for nitrate in groundwater at the watershed scale (Nolan 2001). The concept of establishing a nitrate groundwater pollution hazard index is also appropriate at the farm scale (UC Center for Water Resources, 2004). Estimates of vulnerability can be separated into intrinsic vulnerability and specific vulnerability (National Research Council, 1993). Intrinsic vulnerability is related to factors of which the grower has no control such as soil properties, hydrologic factors, and irrigation water quality. For a given crop, the crop has an intrinsic vulnerability for salinity or specific ion toxicity. Specific vulnerability is a function of management factors such quantity, rate, and method of water and fertilizer applications and other management factors that can be controlled by the farmer.

A wastewater reuse hazard index (WRHI) was developed by Bali and Duqqah (2007) to provide farmers in the Jordan Valley with management tools that can be used to reduce the potential negative impact of wastewater on crop productivity. The overlay and index method of UC Center for Water Resources (2004) was used to assign hazard value for each variable that affect crop productivity. Each variable was assigned a hazard value ranging from 0 to 5. The WRHI is a sum of the hazard values of all factors. The following parameters were used to establish hazard indices for various wastewaters in Jordan:

1- Salinity of irrigation water: The relationship between salinity (EC, electrical conductivity is an estimate of salinity) of irrigation water and crop yield is well established (Bali, 2003). In general field crops are more tolerant to salinity than vegetable crops. The hazard index for salinity will is dependent on crop type and salinity of irrigation water. The yield-salinity response functions of Maas and Hoffman (1977) and van Genuchten and Hoffman (1984) were used to generate hazard values based on salinity and crop type. For example a wastewater with salinity of 2 dS/m has no impact on alfalfa yield (alfalfa is moderately sensitive), therefore a salinity hazard value of zero (0) is appropriate. However, the same water is expected to reduce the yield of green bean (sensitive) by 19%, therefore a salinity hazard value of 1 or higher is appropriate for bean.

2- Specific ion toxicity: Some crops are sensitive to specific ions such as Na, Cl, and B. Specific ion toxicity depends on the concentration of the ion in irrigation water, crop type, and in some cases, the type of irrigation system. For example, the toxicity effect is compounded if the crop is irrigated by a sprinkler system but not a problem with drip irrigation. Chloride concentrations in excess of 250 mg/l pose threats to rootstocks on citrus and grapes (Ayers and Westcot, 1985). The hazard index for each of the above ions were dependent on the factors specific to each ion and each crop.

3- Trace elements: Trace elements are generally present at very low concentrations in surface water sources. However, the concentrations are relatively high in wastewater. A hazard index value was established for each major trace element found in wastewater. According to Grattan (2000), the current levels of trace elements found in wastewater in Jordan have little impact on the productivity of agriculture in Jordan at the present time. A hazard value index for each of the major trace elements was established. The index was based on the recommended maximum concentrations of 15 trace elements in irrigation water for the long-term protection of plants and animals (Pratt and Suarez, 1990).

4- SAR: The impact of Sodium Adsorption Ratio on soil structure depends on the value of SAR, EC, and soil type. The impact of SAR-EC on soil infiltration is well documented in the literature. We used the salinity concentration-SAR relationships established by Rhoades (1982) to assign hazard values to various soil types found in the Jordan Valley. A hazard value index was established for SAR, the index was function of EC and soil type.

5- Nutrients: Wastewater is rich in nutrients specially nitrogen and phosphorus. The nutrient hazard index was based on the concentration of plant available levels of N. Another hazard index was established based on the concentration of soluble P in wastewater. Another area of concern is the presence of P in suspended sediment and the potential for algal blooms in waterbodies and potential impact on the irrigation systems (example, clogging of drip emitters).

6- Irrigation system: A hazard index for the irrigation system depends on the type of irrigation system. For example, the hazard value for a surface or flood system is low, while the hazard value for a drip system is relatively high. The potential interactions of other factors such as pH, HCO3, and total suspended solids was considered.

7- Total Suspended solids (TSS). The presence of suspended sediment and other contaminates adsorbed on suspended sediment in waterways has multiple negative impacts on water quality and may cause environmental problems (Davies-Colley and Smith, 2001). The 1998 National Water Quality Inventory ranks suspended solids and sediments as the leading cause for water quality impairment of rivers and lakes in the United States (Swietlik, 2002). The presence of TSS in water depends on many factors. Bali et al. (2005) studied the interaction between TSS and runoff events in agricultural watershed in Southern California. The relationship between TSS and natural runoff events are not well established and depends on the particle size distribution of sediment and flow rate. In Jordan, TSS values are relatively high in late winter and 75% of all farms in Jordan experience significant plugging problems after two years of use (Hagan and Taha, 1997). In addition to the negative impact of TSS on drip filters and emitters, P is tied up in the suspended sediment and increases the potential for algal bloom. A hazard index for sediment will be established, the index will be a function of the particle size distribution of TSS in wastewater (Bali et al., 2005).

Model Assessment

A WRHI model was developed to integrate the above factors to provide growers in Jordan with a single WRHI for a given crop and estimate the maximum amount of wastewater that could be safely used to meet crop water requirements. For example, WRHI between 0 and 10 for a given crop is of relatively minor concern and no extraordinary management measures are required. However when the WRHI for the same crop increases beyond 10 due to high levels of TSS in the water, the grower will get a detailed report on the hazard of TSS and what measures could be used to bring the WRHI to value below 10. For example, when the concentration of TSS is high, the WRHI is 13. The grower can implement a management measure to flush the media filter twice as often when the value of TSS is low. This management measure reduces the WRHI to an acceptable and economical level to sustain agricultural productivity. Another measure that could be used is sedimentation basin.

Figure 1. shows a sample output of the model for five different management strategies that can be implemented to reduce the WRHI for wastewater and the costs associated with each measure. While all of the management measures are effective in reducing the hazard index for specific wastewater, management measure 2 (BMP 2) is the most cost-effective measure.

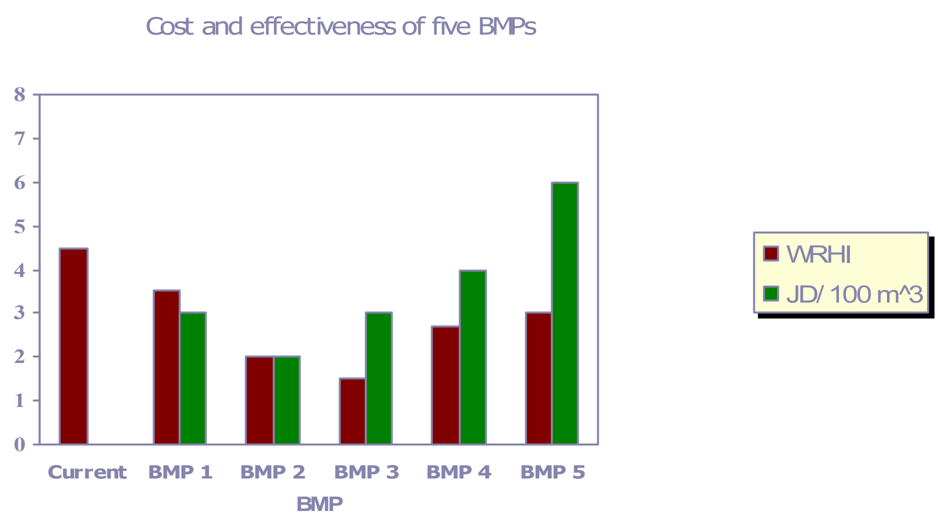

Figure 1. Sample assessment of five management practices to reduced the hazard index of wastewater for a sample farm.

CONCLUSIONS

Irrigated agriculture in Jordan is dependent on wastewater and as a result the quality of marginal water used for irrigation must be suitable for crop production. The availability of treated wastewater for reuse to meet crop water requirements is dependent on water quality, crop type, irrigation system, and other factors. A computer model was developed to predict the potential contribution of wastewater to crop water use of major cash crops in the Jordan Valley. The model incorporates wastewater quality, irrigation system, crop type, and soil type in estimating the maximum potential contribution of wastewater to crop evapotranspiration. The model estimates the potential quantities of wastewater that can be used to supplement fresh irrigation water for various major crops in the Jordan Valley. The model can be used to implement sustainable management strategies for the reuse of treated wastewater in the Jordan Valley.

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